A COMPARATIVE STUDY OF MPPT AND VOLTAGE REGULATOR CONTROLLERS FOR CONTROLLING OUTPUT VOLTAGE IN PV APPLICATIONS

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DEDICATION

"This study is wholeheartedly dedicated to my beloved parents (Mr. **JBER** and Madam **SHAREEFA**), who have been my source of inspiration and gave me strength when I thought of giving up, who continually provide their moral, spiritual, emotional, and financial support. To my brothers (**MUTZ** and **MOHAMMED**), sisters (**MAYADA**, **MOSAH**, and **MARYAM**), who shared their words of advice and encouragement to finish this study. Finally, to my beloved wife **ARWAA** and my children my beloved daughter **ZAHRAA**, my beloved sons **HUSSEIN** and **ABO ALHASAN** thank for all of you"

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ABSTRACT

The demand for renewable energy sources is more and more increasing on each passing year. Since with the increasing number of the human population, the demand for energy is increasing at an alarming state. Petroleum resources are very limited and in this scenario, renewable energy sources such as solar energy proven to be a much more reliable source of energy generation through solar panel technology but getting the most power out of a solar power system is a complicated task and need advanced digital control system and high efficient algorithms. Many algorithms have been developed for the maximum power point tracking (MPPT) of solar panels. However, most of the algorithms such as artificial intelligence and expert systems need high-end computing systems, which are costly and thus not suitable for normal household utilization. In this research, Perturb and Observe (P&O) algorithm with a PI controller algorithm are selected to enhance the MPPT task over the conventional method. This algorithm needs voltage and a current sensor to sense the power parameters of the panel in real time and generate a small difference in duty cycle called perturbation and a boost converter increase or decrease the voltage level based on the PWM signals until the system reach very close to the maximum power point possible. One flaw of this algorithm is that the system never stops at a fixed power point, rather it perturbs around the maximum power range. For further tuning the maximum power point, voltage amplitude and minimize the distortion, a PI controller will be utilized in this research project. Initial results from the solar panel model using SLG-M 350 module are satisfactory. Furthermore, the model has been tested with boost converter circuit in Simulink with a constant duty cycle. Afterward proposed MPPT+PI algorithm results have been compared with simple MPPT method. It is observed that a PI controller minimize the perturbation effect of the MPPT controller largely, which results in less distorted power curves. Additionally, overall power efficiency is increased in the case of proposed MPPT+PI controller, which is 98.5% as compared to 97.8% efficiency of conventional MPPT controller.

ABSTRAK

Tuntutan untuk sumber tenaga yang boleh diperbaharui semakin meningkat dari setahun ke setahun. Disebabkan oleh peningkatan populasi manusia, tuntutan ini semakin meningkat pada kadar yang membimbangkan. Sumber petroleum adalah terhad dan untuk senario ini, sumber tenaga yang boleh diperbaharui seperti tenaga solar dibuktikan merupakan sumber tenaga yang boleh dipercayai melalui teknologi panel solar. Tetapi, menghasilkan sebanyak mungkin tenaga melalui sistem panel solar merupakan satu perkara yang rumit dan memerlukan sistem kawalan digital dan algoritma yang lebih efisien. Pelbagai algoritma telah dibangunkan seperti *Maximum Power Point Tracking (MPPT)* untuk panel solar. Tetapi, algoritma seperti *artificial intelligence* dan sistem yang mahir memerlukan sistem perkomputeran yang jitu yang mahal tidak sesuai untuk kegunaan isi rumah. Melalui kajian ini, algoritma *Perturb & Observe (P&O)* dan algoritma kawalan PI dipilih untuk menigkatkan tugas *MPPT* bila dibandingkan dengan kaedah konvensional. Algoritma ini memerlukan sensor voltan dan arus untuk mengesan parameter kuasa pada penel solar dalam waktu sebenar dan menghasilkan perbezaan sedikit pada gangguan kitaran tugas dalam naik dan turun penukar peringkat voltan berdasarkan signal PWM sehingga sistem mencapai nilai titik kuasa yang tertinggi. Satu kecacatan pada algoritma ini ialah sistem tidak akan berhenti pada titik kuasa yang tetap, malahan menghasilkan gangguan sekitar titik kuasa maksima. Untuk mengubah titik kuasa maksima, amplitude voltan dan mengurangkan gangguan, pengawal PI akan digunakan untuk projek kajian ini. Keputusan awal dari model panel solar menggunakan modul SLG-M 350 agak memuaskan. Selain itu, model ini telah diuiji dengan litar penukar rangsangan di Simulink dengan kitaran tugas yang berterusan. Selepas itu, keputusan algoritma MPPT + PI dibandingkan dengan kaedah MPPT yang mudah. Pengawal PI didapati telah mengurangkan kesan gangguan pengawal MPPT dengan jumlah yang besar, ia mengakibatkan lengkungan kuasa yang kurang diganggu. Tambahan, kecekapan kuasa keseluruhan dinaikkan dalam kes pengawal MPPT + PI pada kes yang telah

dicadangkan iaitu kawalan MPPT + PI, yang benilai 98.5% berbanding efisiensi 97.8% pada pengawal MPPT yang konvensional

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LIST OF SYMBOLS AND ABBREVIATIONS

PV	-	Photovoltaic
MPPT	-	Maximum Power Point Tracking
MPP	-	Maximum Power Point
P&O	-	Perturb and Observe
PI	-	Proportional and Integral
BA	-	Biomass Ash
WEC	-	Wave Energy Converter
Mono-Si	-	Monocrystalline silicon
A-Si	-	Amorphous Silicon
I-V	-	Current – Voltage
P-V	-	Power-Voltage
CCM	-	Continuous Conduction Mode
DCM	-	Discontinuous Conduction Mode
OCV	-	Open Circuit Voltage
SCC	-	Short Circuit Current
AI	-	Artificial Intelligence
ANN	-	Artificial Neural Network
FL	-	Fuzzy Logic
ESC	-	Extremum Seeking Control
Inc. Cond	-	Incremental Conductance

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In recent years, the world's energy request and the number of dispersed production systems have increased. Household and industrial energy production are based primarily on limited resources: oil. As the world's energy demand rises steadily, oil resources are increasingly scarce. The consumption of these sources leads to greenhouse gas emissions, which increases pollution. Moreover, excessive ingesting of natural resource stocks will dangerously reduce the assets of such energy for future generations. Meanwhile, this energy takes a large part of present energy production, it is essential to find alternative solutions to take over. It is estimated that if there is no fundamental change in consumption, the world reserves will be exhausted by 2030 [1].

Therefore, it is extremely important for the utilization of renewable energy systems addendum to the ordinary one, renewable energy sources like solar energy (by using PV) production is widely getting importance because of many advantages like no noise, cost, less maintenance and no fuel, but, the efficiency for PV cell is low and is mostly pretentious due to different atmospheric conditions and load, So, to counter these difficulties and maximize the efficiency, all the design limitations of the PV system are required to be optimized, the P-V and I–V characteristics of PV array are generally very nonlinear, they differ with solar irradiance and temperature that widely affects the PV power output, solar cells convert sunlight into electricity [2]–[5]. Therefore, it can say that solar power is an exceptional prospective solution for the energy crisis.

The benefits of sun PV cells are ease of use in which can generate power once they installed and related, may be set up on a roof of a present structure or be incorporated right into a building, silent and pollution free, electricity may be saved in batteries for use later and generated electricity can be fed into a grid after a few electric methods.

Despite its advantages, PV cells are afflicted by the high preliminary cost, the low efficiency and the requirement of large floor per kW than the conventional supply of power.

Unfortunately, PV panel has non-linear characteristic and there are several factors affecting on PV panels like solar radiation and temperature. In each day, these factors continuously change. In addition, each solar radiation and temperature value has only one maximum power point, maximum power extracts from a photovoltaic cell at this point [6]. If a photovoltaic system is working at MPP, resulting, the achievement for this device is higher.

Therefore, to develop the implementation of a photovoltaic system and extract MPP under any ambient conditions, then it is essential to use control technology to obtain maximum energy. MPPT method calculates MPP for each instantaneous time for any temperature and irradiance. there are many strategies used to implement MPPT from the PV panel they differ in complexity, cost, sensor requisite, speed of convergence, a number of process, and their programs [7]–[9].

One of the most popular methods that use to performed MPPT is (P&O) [10]. P&O technique is dependent on the change of output voltage for a PV panel, and then observes the obtained power to adjust the duty cycle that controls the DC/DC converter to get maximum power, but it suffers from oscillation when reaches to MPP at steady-state and it fails under quickly changing in ambient atmospheric conditions [11]. Therefore, in order to overcome these drawbacks, there is a commonly used control method is a PI controller (proportional and integral) that associated with an MPPT method [1]. PI controller is easy to implement, it is a good way to get better efficiency from a photovoltaic system [3]. PI controller will regulate the input voltage for the DC-DC converter and adjust it to the reference voltage that provides maximum power. A single-diode of a Photovoltaic cell, P&O technique with PI controller and DC-DC BOOST converter to transfer the power produced by the PV module to the load, will be used.

1.2 Problem Statement

Used of photovoltaic module meets several difficulties, PV modules have non-linear characteristics that are determined via temperature and solar irradiance that influence to the general power output of the Photovoltaic modules. Therefore, the photovoltaic panels do not offer constant power supply. To success over these problems, MPPT systems are applied to improve the efficiency of the photovoltaic system; the most popular system is Perturb and Observe.

However, the main drawbacks for P&O technique are: First, energy losses because of the system's operating point oscillate around the MPP at steady-state, the result reduces the efficiency of the PV module. Second, the bad convergence of this technique in the sudden changes in irradiance and/or temperature. Therefore, to overcome these problems, the P&O algorithm with PI controller will use together, to maintaining the DC-link voltage fix and near to its reference rate under changing ambient atmospheric condition.

1.3 Objectives of the Study

(i) To design and perform MPPT P&O system with a DC-DC Boost converter and realize the efficiency in order to get maximum power.

(ii) To design a PI controller to BOOST DC-DC Converter and combine it with MPPT P&O system in order to reduce the oscillation in the output of the converter and improve the efficiency.

1.4 Scope of Project

By using MATLAB SIMULINK:

(i) Photovoltaic model, which represents the source of energy.
Where two mono-crystalline solar panels in series and two in parallel to get 1KW output power (Silfab Solar SLG-M 350 module) is used.

(ii) DC-DC Boost converter to achieve through the PV structure.

(iii) The MPPT controller.

To investigate the idea of conventional P&O system combines with PI controller to get an enhanced MPPT controller.

(iv) To get output power more than 1 KW and output voltage more than 100 V in the case of using MPPT only at temperature 25 ℃ and irradiance 1000 W/m2 then compare these results with results by using MPPT+PI and get improving in these results, in term of reducing the oscillation and improving the efficiency.

1.5 Summary of Chapter

In this chapter discussed the rising of demand for the conventional energy that depends on the oil, decreasing oil sources and the effect of this rising for the future generations (The consumption of these sources leads to greenhouse gas emissions, which increases pollution). After that, discussed alternative sources for this energy, where renewable energy considers a good solution for this issue, like solar energy (by using PV) because of less maintenance, no fuel cost, clean and no noise. However, this energy has non-linear characteristics because it depends on the ambient condition, resulting in low efficiency and it needs to optimize, so the solution is by using MPPT methods to improve the efficiency but also it needs to optimize. One of the most popular methods is P&O method, and then showed its drawbacks in the problem statement part and how can overcome these drawbacks in objective part by using a PI controller. At the end, showed the scopes for this work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Predictable fossil fuels are estimated to finish inside the near future, the sector started out to depend on renewable power as a stress-free, cheap and eternal substitute. Renewable energy is the power, which is to be had in normal resources, which contain sun, earth's crust heat, tides and wind. These sources are renewable and top-up. Different from other conventional energy resources, they have nearly zero carbon emissions, which decrease the global warming disadvantage and greenhouse impact phenomena.

Even though from the critical contaminants those classic energy assets do, fossil fuels amount is reducing hurriedly, and end in the constant-growth in its fee, at the same time as renewable power, properties are everlasting and free. A few years ago, renewable electricity began taking important steps to replace old-style fossil fuel power generation. Figure 2.1 illuminates the renewable power take-part of global energy generation in the year 2010 [12].

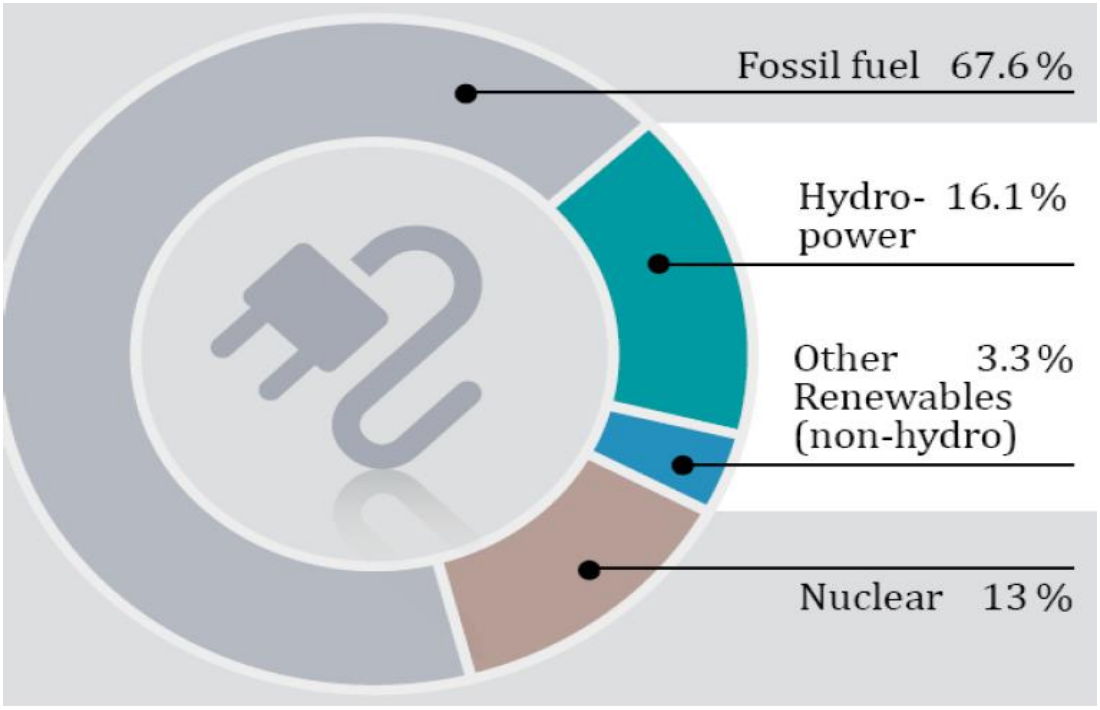

Figure 2.1 Renewable power take-part of global energy generation in the year 2010.

Practically all industries related to normal resources, digging, farming, mining, etc. have a dangerous environmental effect. If we are to collaborate to keep the health of our planet, therefore, finally eliminate this impact [13].

Surrounded by renewable sources of forte, sun power considers an appropriate choice for a variety of requests because of the possibility of straight converting from this system of energy to electric power by using PV structures. So, using photovoltaic structures as a replacement source of energy calls for an excessive quantity of interest. In order to decrease the cost of photovoltaic systems, so, extract maximum power from a PV cell represent an energetic consideration for the best system strategy. At the suitable operating point for PV cell, assume that for a known cell efficiency, the maximum power output is based on load impedance, ambient temperature, and irradiation intensity. There is a one effective point able to give maximum power, and track this point under the change in the radiation and the temperature is important to guarantee the actual action of the PV cell array (Figure 2.2). The main difficulty that is the MPPT has routinely determined the photovoltaic output current or voltage for the photovoltaic array that generates maximum power output for a given irradiance and temperature.

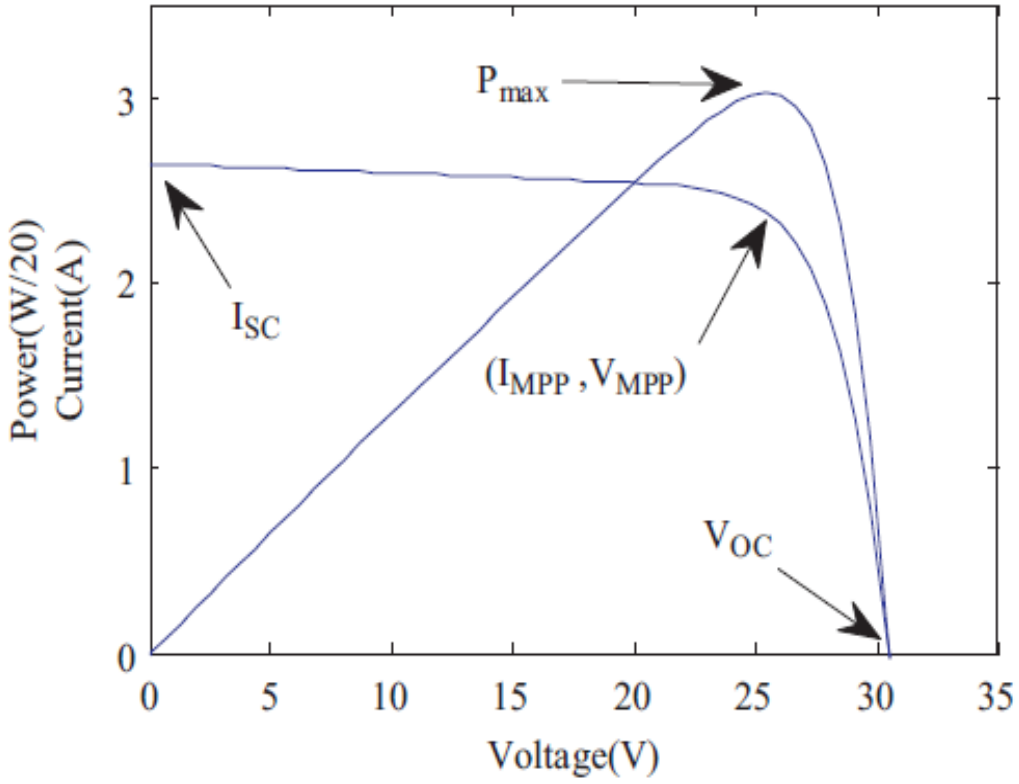

Figure 2.2 I–V and P–V curves of a PV cell

MPPT process may device to improving efficiency, that licenses the system to control at the MPP and can in the right away modify itself to re-track the next MPP when the atmosphere changes [2]. Therefore, many MPPT approaches have been proposed [7]–[9]. P&O technique is the most popular, but it is well known that P&O way exists the trade-off among tracking-time and tracking accuracy.

2.2 Renewable energy forms

2.2.1 Wind power

Power is an important element for socio-economic development. Renewable energy resources like wind power are natural and it can support in decreasing the Dependence on fossil fuels. Power of wind is an indirect style of solar power and continually being refill by the sun. Wind power is producing by variance heating for the surface of the earth by the sun. Wind energy gives a flexible and naturally pleasant superior and nationwide power safety at a time of decreasing fossil fuels for global assets menace

the long-range sustainability regarding the universal economic system. Wind turbine knowledge has remarkable technical features and unique requirements in the approaches used for design. Important progress in wind energy generation design has been achieved due to the development of present technology.

It is possible to generate more electricity from wind energy by structure more wind monitoring places, choosing wind turbines with an appropriate electric wind generator, refining wind turbine conservation procedures to upsurge machine availability, using a huge capacity machine, higher tower height, wider rotor edge sweep area, increase aerodynamics and basic designing, quicker computer processing technology, higher power factor, and better rule, wind energy is predictable for the future of the country plays an progressively vital role in the area of energy, Greenpeace said that by 2020, wind power can deliver about 10% of the electricity source [13].

2.2.2 Solar power

The idea of using solar collectors that catch from the sun's energy was noted in the prehistoric period of 212 (Before Christ) when Greek expert/doctor Archimedes' designed a way for burning the Roman navy by using a mineral mirror in hundreds form of glossy armours; all shiny on the same boat [14]. Solar energy is the power that produces from the sun, which is transmuted in, to heat or electricity. Solar power is the most profuse and cleanest renewable energy sources. Solar knowledge can use this form of energy source for diversity for these purposes, as well as power generation, getting light or a suitable indoor atmosphere, also hot water for household or merchant.

There are some methods of exploitation solar power: solar heating & cooling, PV’s, collecting solar energy and harmful solar. The initial three solar systems are used automatic or electrical equipment to change the heat or light of the sun into an alternative form of existing energy. Harmful solar constructions are applied and oriented to amass stock and distribute thermal energy from sunlight to save occupant well-being without the use of portable accessories or electronic tools[15]. Moreover, there are various sorts of solar asset translation systems used inside the world. The most important one among them is named concentrated solar energy that is used to produce electric power from solar and this power plant brands use of steam strength at

REFERENCES

1. A. Satif, L. Hlou, M. Benbrahim, H. Erguig, and R. Elgouri, “Simulation and Analysis of a Pv System With P and O Mppt,” vol. 13, no. 9, pp. 3014–3022, 2018.

2. B. R. Peng, J. H. Chen, Y. H. Liu, and Y. H. Chiu, “Comparison between Three Different Types of Variable Step-Size P & O MPPT Technique,” no. Cisia, pp. 964–966, 2015.

3. Govind Anil, Nirmal Murugan, and Mufeed Ubaid, “PI Controller based MPPT for a PV \nSystem ,” *IOSR J. Electr. Electron. Eng.* , vol. 6, no. 5, pp. 10–15, 2013.

4. T. K. Behera, M. K. Behera, and N. Nayak, “Spider monkey based improve P&O MPPT controller for photovoltaic generation system,” *Int. Conf. Technol. Smart City Energy Secur. Power Smart Solut. Smart Cities, ICSESP 2018 - Proc.*, vol. 2018-Janua, no. Ic, pp. 1–6, 2018.

5. A. Borni *et al.*, “Optimized MPPT Controllers Using GA for Grid Connected Photovoltaic Systems, Comparative study,” *Energy Procedia*, vol. 119, pp. 278–296, 2017.

6. A. D. Martin and J. R. Vazquez, “MPPT algorithms comparison in PV systems: P&O, PI, neuro-fuzzy and backstepping controls,” *Proc. IEEE Int. Conf. Ind. Technol.*, vol. 2015-June, no. June, pp. 2841–2847, 2015.

7. A. DOLARA, R. FARANDA, and S. LEVA, “Energy Comparison of Seven MPPT Techniques for PV Systems,” *J. Electromagn. Anal. Appl.*, vol. 01, no. 03, pp. 152–162, 2009.

8. A. Reza Reisi, M. Hassan Moradi, and S. Jamasb, “Classification and comparison of maximum power point tracking techniques for photovoltaic

system: A review," *Renew. Sustain. Energy Rev.*, vol. 19, pp. 433–443, 2013.

9. M. A. Eltawil and Z. Zhao, "MPPT techniques for photovoltaic applications," *Renew. Sustain. Energy Rev.*, vol. 25, pp. 793–813, 2013.

10. N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Optimization of perturb and observe maximum power point tracking method," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 963–973, 2005.

11. K. K. Kumar, R. Bhaskar, and H. Koti, "Implementation of MPPT Algorithm for Solar Photovoltaic Cell by Comparing Short-circuit Method and Incremental Conductance Method," *Procedia Technol.*, vol. 12, pp. 705–715, 2014.

12. A. Al Jaber *et al.*, "Corrado Clini Ministry for the Environment and Territory Italy Robert Dixon Climate and Chemicals Team Global Environment Facility Tetsunari Iida Institute for Sustainable Energy Policies Japan World Resources Institute/ Green Independent Power Producers ," 2011.

13. G. M. Joselin Herbert, S. Iniyan, E. Sreevalsan, and S. Rajapandian, "A review of wind energy technologies," *Renew. Sustain. Energy Rev.*, vol. 11, no. 6, pp. 1117–1145, 2007.

14. S. A. Kalogirou, *Solar thermal collectors and applications*, vol. 30, no. 3. 2004.

15. E. Kabalci, G. Gokkus, and A. Gorgun, "Design and implementation of a PI-MPPT based Buck-Boost converter," *Proc. 2015 7th Int. Conf. Electron. Comput. Artif. Intell. ECAI 2015*, pp. SG23–SG28, 2015.

16. R. Ayaz, I. Nakir, and M. Tanrioven, "An Improved Matlab-Simulink Model of PV Module considering Ambient Conditions," vol. 2014, 2014.

17. F. H. Koch, "Hydropower—the politics of water and energy: Introduction and overview," *Energy Policy*, vol. 30, no. 14, pp. 1207–1213, 2002.

18. V. K. Singh and S. K. Singal, "Operation of hydro power plants-a review," *Renew. Sustain. Energy Rev.*, vol. 69, no. November 2015, pp. 610–619, 2017.

19. S. V. Vassilev, C. G. Vassileva, Y. C. Song, W. Y. Li, and J. Feng, "Ash contents and ash-forming elements of biomass and their significance for solid

biofuel combustion," *Fuel*, vol. 208, pp. 377–409, 2017.

20. S. V. Vassilev, D. Baxter, L. K. Andersen, and C. G. Vassileva, "An overview of the composition and application of biomass ash. Part 1. Phase-mineral and chemical composition and classification," *Fuel*, vol. 105, pp. 40–76, 2013.

21. S. V. Vassilev, D. Baxter, L. K. Andersen, and C. G. Vassileva, "An overview of the chemical composition of biomass," *Fuel*, vol. 89, no. 5, pp. 913–933, 2010.

22. M. Izquierdo and X. Querol, "Leaching behaviour of elements from coal combustion fly ash: An overview," *Int. J. Coal Geol.*, vol. 94, pp. 54–66, 2012.

23. D. Moya, C. Aldás, and P. Kaparaju, "Geothermal energy: Power plant technology and direct heat applications," *Renew. Sustain. Energy Rev.*, vol. 94, no. July, pp. 889–901, 2018.

24. M. Ayub, A. Mitsos, and H. Ghasemi, "Thermo-economic analysis of a hybrid solar-binary geothermal powerplant," *Energy*, vol. 87, pp. 326–335, 2015.

25. J. Tan, J. Duan, Y. Zhao, B. He, and Q. Tang, "Generators to harvest ocean wave energy through electrokinetic principle," *Nano Energy*, vol. 48, no. February, pp. 128–133, 2018.

26. a Goetzberger and V. U. Hoffmann, *Photovoltaic Solar Energy Generation*. 2005.

27. A. Mohammad Bagher, "Types of Solar Cells and Application," *Am. J. Opt. Photonics*, vol. 3, no. 5, p. 94, 2015.

28. A. Kuperman, M. Averbukh, and S. Lineykin, "Maximum power point matching versus maximum power point tracking for solar generators," *Renew. Sustain. Energy Rev.*, vol. 19, pp. 11–17, 2013.

29. G. D. A. Jebaselvi and S. Paramasivam, "Analysis on renewable energy systems," *Renew. Sustain. Energy Rev.*, vol. 28, pp. 625–634, 2013.

30. R. K. Kharb, S. L. Shimi, S. Chatterji, and M. F. Ansari, "Modeling of solar PV module and maximum power point tracking using ANFIS," *Renew. Sustain.*

Energy Rev., vol. 33, pp. 602–612, 2014.

31. J. J. Nedumgatt, K. B. Jayakrishnan, S. Umashankar, D. Vijayakumar, and D. P. Kothari, "Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation," *Proc. - 2011 Annu. IEEE India Conf. Eng. Sustain. Solut. INDICON-2011*, no. September 2014, 2011.

32. A. M. Atallah, A. Y. Abdelaziz, and R. S. Jumaah, "I MPLEMENTATION O F P ERTURB A ND O BSERVE MPPT O F PV S YSTEM W ITH D IRECT C ONTROL M ETHOD U SING B UCK A ND B UCK - B OOST C ONVERTERS," vol. 1, no. 1, 2014.

33. W. Xiao, "Photovoltaic Power System," pp. 65–91, 2017.

34. S. Cells, "Optimization of the Function of a Photovoltaic Array Using a Feedback Control System," vol. 13, pp. 107–119, 1984.

35. Z. M. Salameh, F. Dagher, and W. A. Lynch, "Step-down maximum power point tracker for photovoltaic systems," *Sol. Energy*, vol. 46, no. 5, pp. 279–282, 1991.

36. S. Yuvarajan and S. X. S. Xu, "Photo-voltaic power converter with a simple maximum-power-point-tracker," *Proc. 2003 Int. Symp. Circuits Syst. 2003. ISCAS '03.*, vol. 3, pp. 399–402, 2003.

37. S. M. Alghuwainem, "Matching of a DC motor to a photovoltaic generator using a step-up converter with a current-locked loop," *IEEE Trans. Energy Convers.*, vol. 9, no. 1, pp. 192–198, 1994.

38. T. Noguchi, S. Togashi, and R. Nakamoto, "Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic-and-converter module system," *IEEE Trans. Ind. Electron.*, vol. 49, no. 1, pp. 217–223, 2002.

39. C. Zhang, D. Zhao, J. Wang, Y. An, and G. Chen, "A novel two-mode MPPT method for photovoltaic power generation system," *2009 IEEE 6th Int. Power Electron. Motion Control Conf. IPEMC '09*, vol. 3, pp. 2100–2102, 2009.

40. J. J. Nedumgatt, K. B. Jayakrishnan, S. Umashankar, D. Vijayakumar, and D.

P. Kothari, “Perturb and observe MPPT algorithm for solar PV systems-modeling and simulation,” *Proc. - 2011 Annu. IEEE India Conf. Eng. Sustain. Solut. INDICON-2011*, no. December, 2011.

41. A. A. Aminou Moussavou, M. Adonis, and A. Raji, “Design and simulation of solar cell system under different environmental conditions,” *Proc. Conf. Ind. Commer. Use Energy, ICUE*, vol. 2016-Octob, 2016.

42. M. A. Ramadhan, B. W. Harini, N. Avianto, and F. Yusivar, “Implementation of maximum power point tracker algorithm based proportional-integrator controller on solar cell with boost converter circuit,” *Proceeding - ICSEEA 2017 Int. Conf. Sustain. Energy Eng. Appl. "Continuous Improv. Sustain. Energy Eco-Mobility"*, vol. 2018-Janua, pp. 20–24, 2018.

43. F. González-Longatt, “Model of photovoltaic module in Matlab,” *2Do Congr. Iberoam. Estud. Ing. Eléctrica, Electrónica Y Comput. (Ii Cibelec 2005)*, vol. 2006, no. 4, pp. 1–5, 2005.

44. R. Arulmurugan and N. S. Vanitha, “Optimal Design of DC to DC Boost Converter with Closed Loop Control PID Mechanism for High Voltage Photovoltaic Application,” vol. 2, no. 4, pp. 434–444, 2012.

45. S. Avinash and T. R. Jyothsna, “Computation of Simple Robust PI / PID Controller Design for Time-delay,” no. 2, pp. 257–265, 2017.

46. A. P. Submitted, I. N. Partial, O. F. The, R. For, and T. H. E. Degree, “STUDY OF MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUES IN A SOLAR PHOTOVOLTAIC ARRAY STUDY OF MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUES IN A SOLAR,” pp. 1–49.

47. G. Anil, N. Murugan, and M. Ubaid, “PI Controller based MPPT for a PV System,” *IOSR J. Electr. Electron. Eng.*, vol. 6, no. 5, pp. 10–15, 2013.

48. F. Yusivar and B. Tito, “Solar Cell MPPT Technique Based on PI Controller,” *Adv. Mater. Res.*, vol. 608–609, pp. 89–96, 2012.

49. M. Q. Duong, V. T. Nguyen, G. N. Sava, M. Scripcariu, and M. Mussetta, “Design and Simulation of PI-Type Control for the Buck Boost Converter,”

Proc. 8th Int. Conf. Energy Environ. Energy Saved Today is Asset Futur. CIEM 2017, vol. 2017, no. 11, pp. 79–82, 2018.

50. B. R. Copeland, “The Design of PID Controllers using Ziegler Nichols Tuning,” no. March, pp. 1–4, 2008.